U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-281 490

Industrial Process Profiles for Environmental Use: Chapter 23. Sulfur, Sulfur Oxides and Sulfuric Acid

Radian Corp, Austin, Tex

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio

Feb 77

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-023w	2.
3. RECIPIENT'S ACCESSION NO. PB281490	
4. TITLE AND SUBTITLE Industrial Process Profiles for Environmental Use: Chapter 23. Sulfur, Sulfur Oxides and Sulfuric Acid	5. REPORT DATE February 1977 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard W. Gerstle and Vishnu S. Katari (PEDCo) Terry Parsons and Charles Hudak, Editors	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation 8500 Shoal Creek Boulevard P.O. Box 9948 Austin, Texas 78766	10. PROGRAM ELEMENT NO. 1AB015: ROAP 21AFH-025 11. CONTRACT/GRANT NO. 68-02-1319, Task 34
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory Office of Research and Development U.S. ENVIRONMENTAL PROTECTION AGENCY Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Initial: 8/75-11/76 14. SPONSORING AGENCY CODE EPA/600/12
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

The catalog of Industrial Process Profiles for Environmental Use was developed as an aid in defining the environmental impacts of industrial activity in the United States. Entries for each industry are in consistent format and form separate chapters of the study.

The sulfur industry is divided into two basic parts, according to the types of products. The first part involves those chemical processes which yield elemental sulfur either from naturally occurring deposits or from hydrogen sulfide containing gas streams. The elemental sulfur serves as one of the main raw materials for the sulfur oxides and sulfuric acid production plants which comprise the second part of the industry. Three industrial process flow diagrams and twelve process descriptions have been prepared to characterize the industry. Within each process description available data have been presented on input materials, operating parameters, utility requirements and waste streams. Data related to the subject matter, including company and product data, are included as appendices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Sulfur Elemental Sulfur Hydrogen Sulfide Sulfur Oxides Sulfuric Acid Frash Process Claus Process Sour Gas Process Description	Air Pollution Control Water Pollution Control Solid Waste Control Stationary Sources Fertilizer Industry	07B 13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified 20. SECURITY CLASS (This page) Unclassified	21. NO. OF PAGES 95 22. PRICE PCA04 MFA01

EPA Form 2220-1 (9-73)

*USGPO: 1978 — 757-086/0807

PB 281 490

EPA-600/2-77-023w
February 1977

Environmental Protection Technology Series

INDUSTRIAL PROCESS PROFILES FOR ENVIRONMENTAL USE: Chapter 23. Sulfur, Sulfur Oxides and Sulfuric Acid

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SPRINGFIELD, VA. 22161

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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EPA-600/2-77-023w
February 1977

INDUSTRIAL PROCESS PROFILES

FOR ENVIRONMENTAL USE

CHAPTER 23

SULFUR, SULFUR OXIDES AND SULFURIC ACID

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ACKNOWLEDGMENTS

This catalog entry was prepared for EPA by PEDCo-Environmental Specialists, Inc., under Contract No. 68-02-1321, Task 25. Vishnu S. Katari and Richard W. Gerstle were the co-authors of this report.

SULFUR, SULFUR OXIDES AND SULFURIC ACID INDUSTRY

INDUSTRY DESCRIPTION

The sulfur, sulfur oxides and sulfuric acid plants comprise a large and important chemical industry. The principal product of the sulfur industry[a] is concentrated sulfuric acid which serves as a raw material in numerous applications. Sulfuric acid accounts for over 90 percent of domestic sulfur production.[1] Other products of importance include, but are not limited to, sulfur dioxide and oleum.

The sulfur industry has expereienced steady growth during the previous 25 years, with an increase in total annual production for 6.1 to 11.2 million metric tons since 1950.[2] Forecasts indicate that the domestic sulfur demand will increase to between 23 to 38 million tons by the year 2000. Despite this long term trend, production in 1975 slipped 1.4 percent of the 1974 levels.[2] Exports and imports are roughly equivalent and represent only 10 percent of domestic consumption.[2]

The sulfur industry can be divided into two basic groups according to the types of products. Chemical processes yielding elemental sulfur either from naturally occurring deposits or from H_2S containing gas streams, comprise the first group. The elemental sulfur serves as one of the main raw materials for the sulfur oxides and sulfuric acid production plants which comprise the second major category.

The Frasch Process continues to be the dominant source of elemental sulfur, accounting for 64 percent of domestic production in 1975.[2] This process, which is technically similar to the original process introduced in the 1890's, provides an economical supply of high purity (99.5 + %) sulfur. Impurities such as hydrocarbons and ash generally are present in quantities less than 0.15 percent each.[3] There are presently 13 Frasch mines in the United States, all located in Texas and Louisiana.[4] The annual quantities of Frasch sulfur produced

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[a] Throughout this report the term "sulfur industry" will apply to all components of the elemental sulfur, sulfur oxides and sulfuric acid industries.

domestically have been relatively stable at 5 to 6 metric tons during the last ten years.[2] Nevertheless, the share of the elemental sulfur market has declined steadily during this period due to increases in recovered sulfur.

Recovered elemental sulfur from both natural gas purification and petroleum processing accounted for 26 percent of domestic 1975 production. Quantities from both sources have approximately doubled in the previous 5 years.[2] Unlike the Frasch process, which is concentrated in a small geographical region, recovered sulfur plants are widely distributed. There are approximately 140 plants, located in all major industry regions of the country.[4] Such plants tend to be small, with only five of the 140 plants having production capacities in excess of 100,000 tons per year.[4]

There are approximately 166 sulfuric acid plants with an annual production capacity of 37.5 million tons; 7 plants produce more than a million tons annually.[4] Of the 28.8 million tons of sulfur acid produced in 1973, 99.6 percent was by the contact process and the remainder by the chamber process.[5] About 68 percent of contact process sulfuric acid was produced from elemental sulfur, 4.5 percent from iron pyrites, 9 percent from smelter tail-gas, and 18.5 percent from hydrogen sulfide spent alkylation acid, and acid sludge from refineries.[4] Additionally, by-product sulfuric acid is produced by several copper, lead and zinc smelters.

In 1974, there were about eight sulfur dioxide producers with a total capacity of 204,000 tons.[4] About 45 percent of the total sulfur dioxide was used in producing hydrosulfites and other chemicals, 25 percent in paper manufacturing, and the remainder in soybean protein production, oil refining, metal and ore refining, and other miscellaneous processes.[6]

Raw Materials

The main source of raw elemental sulfur is the large sulfur deposits in the coastal plains of Louisiana and Texas. The Frasch sulfur produced in this region accounted for 64 percent of domestic sulfur production in 1975.[2] Recovered elemental sulfur from natural

gas and petroleum processing provided 26 percent of domestic production, and recovered sulfuric acid accounted for the remaining 10 percent. There has been a modest but steady decline during the last 25 years in the fraction of elemental sulfur provided by the Frasch process. In 1950, over 85 percent of sulfur was produced by the Frasch process while the present level is only 64 percent.[2] There was a drop from 69 percent to 64 percent in the previous year alone.[2]

Treatment of sour natural gas and refining of petroleum results in the recovery of hydrogen sulfide as a by-product, which subsequently can be used for production of sulfur and sulfur oxides. The quantities of elemental sulfur recovered at natural gas plants and petroleum refineries are approximately equal.[2] Both sources have experienced rapid growth during the last five years.[2]

Concentrated sulfur dioxide in the gaseous effluent of non-ferrous smelters is a third major sulfur source. These gases generally contain 4 to 8 more percent SO_2. There is a long term trend toward more recovery of SO_2 from smelters and power plants due partially to environmental control requirements.

Products

Sulfuric acid is the major product of the sulfur chemicals industries, accounting for over 90 percent of total domestic sulfur consumption.[2] Other products include oleum, sulfur dioxide and sulfur. One relatively minor by-product of this industry is iron calcite produced when pyrites are used as a raw material.

Elemental sulfur is chemically stable and can be stored for long periods of time without any appreciable product quality degradation. It has a characteristic yellow color and is generally shipped in the liquid form to facilitate handling and to reduce environmental impact. All but a small fraction of elemental sulfur is ultimately consumed for production of sulfuric acid.

Sulfuric acid is a colorless, corrosive, oily liquid obtained in a variety of different commercial grades. Table B-1 in the appendices shows the major users of sulfuric acid by industry group. It can be seen that fertilizers are by far the major end products. Oleum or

fuming sulfuric acid is a solution of sulfur trioxide in 100 percent sulfuric acid. Oleum, which reacts very violently with water, is highly toxic. It is used as a sulfating and sulfonating agent; as a dehydrating agent in nitrations; in the dye, explosive, and petroleum refining industries; and as a laboratory reagent.[7] Table B-2 gives properties of the commercial grades of sulfuric acid and oleum.

Sulfur is a colorless gas with a pungent odor which is primarily used in the food and chemical industries. Anhydrous grade sulfur dioxide is at least 99.98 percent pure.

Physical properties of sulfur, sulfur oxides and sulfuric acid are summarized in Table B-3.

Companies

There is a very large and diverse set of companies involved in the production of sulfur chemicals. In addition to the elemental sulfur companies using the Frasch process, there are oil companies, chemical companies and non-ferrous smelting companies which recover sulfur or sulfur oxides.

The leading producers of Frasch sulfur and the corresponding production capacities are listed in Table 1. Freeport Sulfur Company and Texas Gulf Sulfur Company together accounted for 60 percent of the total sulfur production in 1973.[4] It is apparent that this segment of the industry is concentrated entirely in the Gulf Coast area, where large deposits of sulfur bearing ore are available. Frasch sulfur production facilities are generally large scale operations due to the utilities requirements.

There are over fifty companies actively involved in the production of elemental sulfur from either sour natural gas or petroleum. A list of plants and production capacities is provided in Appendix A-1. It is apparent that such plants tend to have smaller production capacities than the Frasch sulfur facilities. Only 5 of the elemental sulfur recovery plants had capacities in excess of 100,000 tons per year while all but one of the Frasch plants is substantially larger than this amount. Approximately 55 percent of the sulfur recovery plants was produced at

Table 1. LEADING PRODUCERS OF FRASCH-SULFUR AND THEIR PRODUCTION CAPACITIES
(SOURCE: REFERENCE 4)

Producer	Capacity, 10^3 metric ton/yr
Arco Chemical, Fort Stockton, Texas	183
Duval, Culberson County, Texas	2,540
Freeport, Garden Island, La.	813
Freeport, Grand Ecaille, La.	1,422
Freeport, Grand Isle, La.	1,524
Freeport, Lake Pelto, La.	610
Jefferson Lake, Long Point, Texas	305
Pan American Petroleum, High Island, Texas	51
Texas Gulf, Bullycamp, La.	305
Texas Gulf, Fannett, Texas	178
Texas Gulf, Moss Bluff, Texas	305
Texas Gulf, Newgulf, Texas	1,524
Texas Gulf, Spindletop, Texas	686
Total	10,446

Table 2. FIVE LARGEST RECOVERED-SULFUR PRODUCERS - 1973
(ADAPTED FROM REFERENCE 4)

Producer	Capacity, 10^3 metric ton/yr
Exxon Company	260
Getty Oil Company	231
Shell Oil Company	1,077
Standard Oil Company of California	165
Standard Oil Company of Indiana	464
Total	2,197

petroleum refineries (38 companies total) and 45 percent at natural gas purification plants (29 companies total).[2] The five largest recovered sulfur produced (both petroleum and natural gas processing) are listed in Table 2. Due partially to the relatively high sulfur content of some mideastern crude oil, there should be continual growth in sulfur recovery. Since 1970, the quantities produced from both natural gas and petroleum have doubled.[2]

There are three general categories of companies involved in the production of sulfuric acid; the elemental sulfur (Frasch) companies, chemical companies and non-ferrous smelting companies. The capacities and raw materials vary significantly as illustrated in Table 3.

A comparison of the totals of raw materials listed in Table 3 indicate that Frasch sulfur now accounts for only slightly more than half of total sulfur consumed. This trend toward more recovered sulfur and reclaimed sulfuric acid should continue due to environmental regulations. During the next ten years coal and oil fired utility boilers equipped with certain SO_2 control systems could become sulfur and sulfuric acid sources.

Sulfur dioxide is produced by 6 companies at eight sites in Table 4. It is apparent that this volume of sulfur dioxide produced is an order of magnitude lower than sulfuric acid.

In 1974, four companies were manufacturing sulfur trioxide: Allied Chemical Corporation, (Industrial Chemical Division); E.I. du Pont Company, (Industrial Chemicals Division); Cities Service Company; and Stauffer Chemical Company, (Industrial Chemical Division).[4]

More complete lists of producers of elemental sulfur, sulfur dioxide, sulfur trioxide, sulfuric acid, and other products are listed in Tables A-1 through A-5 in the appendices.

Environmental Impact

Atmospheric emissions of H_2S, SO_2 and sulfuric acid mist constitute the main environmental problem with the various sulfur chemical industries. In sulfuric acid production the SO_2 emissions vary inversely with the SO_2 to SO_3 conversion efficiency. For older sulfur-burning plants with three-stage converters, conversion efficiencies

Table 3. MAJOR SULFURIC ACID PRODUCERS

(Adapted from reference 4)

Producer	Quantities of Sulfuric Acid, 1000 metric tons/year			
	Using Elemental Sulfur	Using Smelter Gas (SO_2)	Using sludge pyrites, hydrogen sulfide	Total capacity
Chemical companies				
Stauffer Chemical Co.	710	-	2,972	3,682
Allied Chemical Co.	1,197	-	1,539	2,736
E.I. duPont	1,095	-	1,302	2,397
C.F. Industries	2,086	-	-	2,086
Farmland Industries, Inc.	1,179	-	-	1,179
Gardinier, Inc.	1,361	-	-	1,361
Elemental sulfur companies				
Freeport Minerals, Inc.	1,542	-	-	1,542
Texasgulf, Inc.	1,343	-	-	1,343
Non-ferrous smelters				
American Smelting and Refining	-	636	-	363
Kennecott Copper	-	975	-	975
Phelps Dodge	-	426	-	426
St. Joe Mineral	-	350	-	350
Anaconda	-	313	-	313
Bunker Hill	-	287	-	281
Total	10,513	2,981	5,813	19,307

Table 4. DOMESTIC SULFUR DIOXIDE PRODUCERS

(Source: Reference 4)

Producer	Capacity 10^3 metric ton/yr
Ansul, Marinette, Wisc.	15
Asarco, Tacoma, Washington	61
Cities Service, Copperhill, Tenn.	35
Essex, Newark, N.J.	15
Stauffer, Baton Rouge, La.	13
Stauffer, Hammond, Ind.	10
Virginia Chemicals, W. Norfolk, Va.	41
Virginia Chemicals, Selby, Calif.[a]	14
Total	204

[a]May be shut down.

are typically 95 to 96 percent, with corresponding emissions of approximately 22 to 37 kilograms of SO_2 per ton of acid produced (approximately 7800 to 15,600 mg/m^3 (3000 to 6000 ppm).[8,9] Conversion of efficiencies for four-stage converters range from 96 to 98 percent, with SO_2 emissions between 11 and 29 kilograms per ton (approximately 3900 to 10,400 mg/m^3, 1500 to 4000 ppm).[8,9] Plants utilizing elemental sulfur as feed generally have lower emissions compared to plants using other sulfur-bearing feed streams. Dual absorption plants can achieve conversion efficiencies higher than 99 percent, with resulting SO_2 emissions of less than 2.0 kilograms per ton of acid. The corresponding SO_2 concentration are less than 1300 mg/m^3 (500 ppm) with such plants. Acid mist emissions are in the range of 0.5 to 6 kg per ton of acid without controls and are independent of conversion efficiencies.

Sulfur dioxide emissions from new sulfuric acid plants are limited by Federal regulations to 2.0 kg per ton of acid produced; acid mist emissions are limited to 0.075 kg per ton of acid.

Some odorous compounds are emitted from plants that utilize feedstocks with large amounts of organic compounds such as refinery acid sludges. These organic compounds are largely oxidized in the combustion and conversion stages of the sulfuric acid manufacturing process, but trace amounts may be emitted.

Chamber-type sulfuric acid plants generally release lower concentrations of sulfur dioxide as compared to contact plants. The exit gases in the chamber plant, in addition to SO_2, contain between 1230 to 2460 mg/m^3 (1000 to 2000 ppm) of nitrogen oxides. The air pollution impact caused by chamber processes is limited by the small quantities produced in this manner. Chamber type production accounts for only 0.4 percent of the total sulfuric acid production.

Emissions from Claus type plants used to process H_2S recovered from natural gas or petroleum include H_2S, SO_2, carbonyl sulfide and carbon disulfide.[10] For a typical 100 metric ton per day, operating at 94 percent efficiency, H_2S and SO_2 concentration would be 11,900 and 23,900 mg/m^3 (8500 and 9200 ppm), respectively.[11] Carbonyl sulfide

and carbon disulfide concentrations are estimated at roughly 1250 mg/m^3 (500 ppm) each. Conventional treatment practice is incineration in order to reduce potential odor problems in the vicinity of the Claus plant. This results in a substantial increase in SO_2 emission rates and concentration. There are a variety of tail-gas treatment problems under development to alleviate these atmospheric problems. Most of these processes recover sulfur pollutant compounds in a chemical form that can be used. These tail-gas processes generally reduce sulfur compound emissions by 80 percent or greater. Literature concerning the operating conditions and performance characteristics of these processes is provided in references 10, 11, 12, 13, 14 and 15.

Liquid and solid waste impacts caused by this industry are minimal. Accidental spills of sulfuric acid which is shipped by rail, train and barge can cause physical damage to the surrounding areas.

Bibliography

1. Merwin, R. W. and W. F. Keyes. Sulfur and Pyrites. Bureau of Mines Minerals Yearbook, U.S. Department of the Interior. 1973.

2. Sulfur in 1975. Division of Nonmetallic Minerals. In: Mineral Industry Surveys, U.S. Department of the Interior, Bureau of Mines. Washington, D.C. July 10, 1976. 17 p.

3. Lowenheim, F. A. and M. K. Moran. Faith, Keyes and Clarks' Industrial Chemicals, fourth edition, Wiley Interscience, 1975.

4. Stanford Research Institute. 1974 Dictionary of Chemical Producers - United States of America. California, 1974.

5. Chemical Economics Handbook. Manual of Current Indicators. Stanford Research Institute. California, February 1975.

6. Chemical Profile - Sulfur Dioxide. In: Chemical Marketing Reporter, No. 9. August 26, 1974. Schnell Publishing Co., Inc. New York.

7. Hawley, G. G. The Condensed Chemical Dictionary. Eighth edition. Van Nostrand-Reinhold Company. New York, 1971.

8. Background Information for Proposed New-Source Performance Standards: Sulfuric Acid Plants. EPA Office of Air Programs, Research Triangle Park, N.C. August 1971. Report No. APTD-0711.

9. Chemical Construction Corp., Engineering Analysis of Emissions Control Technology for Sulfuric Acid Manufacturing Process. NTIS No. PB190393. March 1970.

10. Semrau, K. T. Control of Sulfur Oxide Emissions from Primary Copper, Lead, and Zinc Smelters--A Review. (For Presentation at the 63rd Annual Meeting of the Air Pollution Control Association. Missouri. June 14-18, 1970.)

11. Genco, J. M. and S. S. Tam. Characterization of Sulfur Recovery from Refinery Fuel Gas. EPA Contract No. 68-02-0611. June 1974.

12. Beavon, D. K. and R. N. Fleck. Beavon Sulfur Removal Process for Claus Plant Tail Gas. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfeiffer (ed.). Washington, D.C., Advances in Chemistry Series 139, American Chemical Society, 1975. p. 93-99.

13. Barthel, Yves, et al. Sulfur Recovery in Oil Refineries Using IFP Processes. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfeiffer (ed.). Washington, D.C., Advances in Chemistry Series 139, American Chemical Society, 1975. p. 100-110.

14. Swaim, C. D., Jr. The Shell Claus Offgas Treating (SCOT) Process. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfeiffer (ed.). Washington, D.C., Advances in Chemistry Series 139, American Chemical Society, 1975. p. 111-119.

15. Kim, B., Genco, J. M., Oxley, J. and P. Choi. Development of Information for Standards of Performance for the Fossil Fuel Conversion Industry. EPA-450/3-75-029, October 1974.

INDUSTRY ANALYSIS

The sulfur, sulfur oxides and sulfuric acid industries are logically divided into two segments. The production of elemental sulfur from either naturally occurring deposits or hydrogen sulfide containing gas streams constitutes the first group of processes. The elemental sulfur produced serves as the main raw material to the sulfur acid and sulfur dioxide industries which comprise the second major group.

Elemental sulfur is produced primarily by Frasch Process recovery of natural deposits or Claus Process recovery from sour gas streams. Power plant desulfurization processes may eventually be another source of elemental sulfur, however, these processes have not yet achieved commercial status in the United States. For this reason, such desulfurization processes are not discussed.

Sulfuric acid is produced by the contact process from burning sulfur, or H_2S, from metallurgical smelter gases, roaster gases, burning of acid sludges, and other minor sources. In all cases the same overall reaction mechanisms occur. The chamber process of producing sulfuric acid is not discussed, because the process is becoming obsolete and presently accounts for only 0.4 percent of production.

ELEMENTAL SULFUR PRODUCTION

Elemental sulfur is produced by two general methods: 1) the Frasch Process of recovery of naturally occurring sulfur and 2) the Claus Process of oxidation of H_2S recovered from natural gas plants and petroleum refinery. The Frasch Process continues to be the dominant process despite recent gains in recovered sulfur production. Due to the high sulfur content of some Mideast oil and to stringent environmental regulations, the trend in favor of recovered sulfur should continue. Generalized process flowsheets for these two techniques are presented in Figures 1a and 1b.

The hydrogen sulfide recovery process has been subject to rapid technological development due to the increasing cost of Frasch sulfur and to the need for such processes in coal gasification. The process actually encompasses a series of steps, including removal of H_2S from a gas stream, oxidation of the H_2S, and recovery of the elemental sulfur. These have been lumped into one process block since there are generally no major waste streams from the H_2S removal processes. The discussion of gas stream desulfurization is limited to the various amine techniques since it is the dominant approach at the present. It should be noted that there are a large number of other processes which could be used and that the input materials and utilities requirements will vary.

Hydrogen sulfide oxidation and elemental sulfur recovery is typically done in a Claus plant. Due to the predominance of this general technique, it is the only process discussed. The Stretford Process is a possible alternative to the Claus Process, particularly in applications with a low H_2S concentration gas stream from the desulfurization process.

Gaseous emissions from the Claus plant have generally been incinerated to convert H_2S to the less odorous compound SO_2. Increasing concern over ambient SO_2 levels has resulted in greater interest in tail gas treatment processes for removal of all sulfur compounds. There are relatively few commercial installations in the United States despite the fact that a number of processes have been successfully

operated in Europe. A general discussion of these processes is presented since there are too many to cover separately. Useful references which provide a convenient entry to the technical literature concerning tail gas processes is also presented.

The Frasch Process is a highly developed commercial process not subject to rapid technological changes. Furthermore, this industry does not have the diversity which characterizes the sulfur recovery industry.

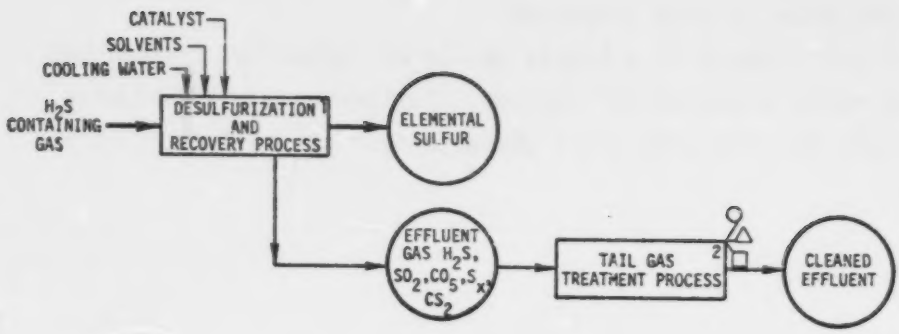

Figure 1a. Sulfur production from gas treatment.

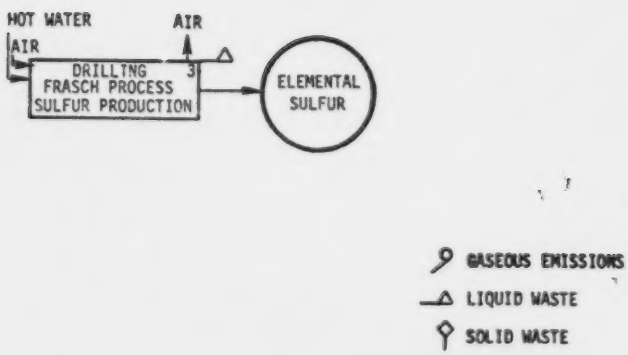

Figure 1b. Sulfur production from Frasch sulfur.

Gas Desulfurization and Sulfur Recovery

1. Function - This process comprises a series of steps designed to remove sulfur compounds from a natural gas plant or petroleum refinery gas stream and to convert those sulfur compounds to elemental sulfur. Desulfurization may be accomplished in a variety of techniques, however, recovery using ethanamine is the most common. Applicable chemical reactions for this process are shown below.[1]

$$2\ RNH_2 + H_2S \rightleftharpoons (RNH_3)_2\ S$$

$$(RNH_3)_2\ S + H_2S \rightleftharpoons 2\ RNH_3\ HS$$

The term R in these equations represents a variety of organic groups. Principal amine compounds used in these processes are monoethanolamine (MEA), diethylanolamine (DEA), diisopropanolamine (DIPA), and 2(2-aminethoxy ethanol) (DEA).[1] The choices of amine sometimes depends on the presence of other sulfur compounds. Diethylanolamine is used for refining gas (10 to 20 percent aqueous solution) while monoethanolamine is generally used for purification of natural gas (10 to 30 percent aqueous solution).

The regenerated acid gas stream composed primarily of CO_2 and H_2S can be treated in a Claus unit for production of elemental sulfur. There are a variety of process configurations which can be used depending on the H_2S concentration in the inlet gas stream. These include total acid gas combustion and split stream combustion. The basic chemical processes in all of these systems are similar and are presented below.[2]

$$H_2S + \frac{3}{2}\ O_2 \longrightarrow SO_2 + H_2O$$

$$2\ H_2S + SO_2 \longrightarrow 3\ S + 2\ H_2O$$

$$\text{Overall } H_2S + \frac{1}{2}\ O_2 \longrightarrow S + H_2O$$

In total combustion, the acid gas stream is mixed with the theoretical amount of air and burned in a combustion chamber. Products of combustion containing sulfur vapor, steam, SO_2, and H_2S are passed through a heat recovery boiler, where partial cooling of combustion gases occurs

and a portion of the sulfur vapor is condensed and separated. Effluent gases are passed to a two- or three-stage catalytic converter with provision for intermediate condensation and reheating. The reaction is carried out in the presence of a bauxite catalyst and additional sulfur vapor is formed and condensed. All the product sulfur formed in the heat recovery boiler and condensers is passed to a liquid sulfur storage tank after passing through a coalescer.

The split-stream combustion process consists of burning one-third of the feed acid gas stream in the furnace to produce SO_2. This SO_2 is then combined with the remaining two-thirds of feed material and passed to a catalytic reactor where the reaction between SO_2 and H_2S occurs. The reaction products enter a heat exchanger where the sulfur is condensed. The reaction gas is then passed through a coalescer to remove any entrained droplets of sulfur which could interfere with subsequent gas treatment equipment (incineration or tail-gas purification systems).

Usually the sulfur recovery in Claus units is 94 to 97 percent, the percentage being affected by the number of catalyst stages. About 85 percent conversion is achieved in a one-stage converter, 94 percent in a two-stage converter, and 97 percent in a three-stage converter. Recovery efficiency also varies directly with the H_2S concentration of the feed gas. The sulfur recovered from gases in a Claus-type recovery plant usually is above 99.9 percent pure and is free of metallic contaminants such as arsenic, selenium and tellurium.

2. Input Materials - A gas stream containing H_2S from natural gas plants, petroleum refineries or other sources is the main input stream. Steam from H_2S stripping is required along with make-up amine solution.

Air requirements for the Claus plant are approximately 1800 m^3 per metric ton of sulfur recovered.

Feed to the sulfur recovery plant primarily contain hydrogen sulfide and carbon dioxide with about 1 to 2 mole percent of hydrocarbons.[3] Table 5 shows material flow quantities for typical Claus sulfur plants on a petroleum refinery gas stream.[2]

Table 5. MATERIAL FLOW FOR EXAMPLE CLAUS SULFUR PLANT

Feed quantity m^3/day	65,000
Feed composition, mole %	
H_2S	90
CO_2	8
Hydrocarbons	2
Sulfur production, metric tons/day	122
Air, m^3/metric ton	1,800

The catalyst used is a natural bauxite that has been activated by heating to a temperature between 370 to 400°C and calcined to a residual water content of 6 percent.[4] For split-stream combustion a ratio by volume of catalyst to H_2S to be converted may be 1:2 or more.[5] The catalyst is usually replaced annually.

3. Operating Parameters - H_2S absorption is generally performed at 40°C and atmospheric pressure while stripping is done at roughly 110°C. The Claus plant operates an atmospheric pressure with an intake gas temperature of 40°C. The temperature in the burner reaches 1100°C. After passing through a waste heat boiler, the gas temperature is about 370°C. The temperature of the gas in the converter is maintained between 230 and 245°C. The condenser gas exit temperature is 150°C.[6]

4. Utilities - Approximately 2 horsepower per ton of product is needed for lighting and miscellaneous purposes.[7] Fuel gas is required for start-up of the sulfur plant. Boiler feed water requirements of Claus plants are: 1300 kg/hr for a plant of 10 tons/day recovery, 12,000 kg/hr for a plant of 100 tons/day capacity, 58,000 kg/hr for a plant of 500 tons/day capacity, and 111,000 kg/hr for a plant of 1000 ton/day capacity.[8] Table 6 gives fuel requirements and steam generation for the plants described in Table 5.[9]

Table 6. FUEL REQUIREMENTS

	Plant A	Plant B	Plant C
Fuel gas, m^3/day	14,200	5,400	7,000
Steam generated, kg/hr	15,000	16,000[a]	4,000

[a]Consisting of about 12,000 kg/hr of 21.1 kg/cm^2 steam and about 400 kg/hr of 3.5 kg/cm^2 steam.

The reactions are highly exothermic. Most of the heat generated in the burner and reaction chamber is removed by generating high-pressure steam, and the condenser heat is removed by generating low-pressure steam.[10]

5. Waste Streams - Waste streams for this process are based on a single-stage recovery unit with one catalytic reactor. The vent gases from the sulfur recovery unit may contain 1 to 3 mole percent of unconverted H_2S and SO_2.[4] Unrecovered sulfur appears in tail gases principally as H_2S, sulfur vapor and SO_2. A typical tail gas from a properly designed and operated Claus unit will contain CO_2, N_2 and H_2O plus sulfur compounds in concentrations shown in Table 7.

Table 7. CLAUS SULFUR PLANT TAIL GAS

Components	Composition range, ppm dry basis	Composition range, mg/m^3
H_2S	5,000 to 12,000	7,000 to 17,000
SO_2	2,500 to 6,000	6,500 to 16,000
CS_2	300 to 5,000	950 to 16,000
COS	300 to 5,000	730 to 12,250
S_8 (vapor)	100 to 200	1,000 to 2,000

Because the feed gas may contain carbon/sulfur compounds, reactions in the process will result in carbonyl sulfide and carbon disulfide. Increasing hydrocarbon content of the feed stream will tend to increase the formation of COS and CS_2. These carbon/sulfide compounds can be minimized but not eliminated by reducing the hydrocarbon content of the

feed. CO_2 can also be a source of carbon for forming sulfides.[11]

Many methods are available to control the emissions. The methods used most often in the United States are flaring and incineration which convert the sulfides to sulfur dioxide. Tail gas clean-up processes are now commercially available to aid in reducing sulfur emissions.

Solid waste in the form of inactive catalyst is also generated at Claus plants.

6. EPA Source Classification Code - None exists.

7. References -

1. Kim, B., Genco, J. M., Oxley, J. and P. Choi. Development of Information for Standards of Performance for the Fossil Fuel Conversion Industry. EPA-450/3-75-029, October 1974.

2. Air Pollution Engineering Manual. U.S. Environmental Protection Agency Report AP-40, 1972.

3. Grekel, H., Palm, J. W. and J. W. Kilmer. Why Recover Sulfur from H_2S? In: The Oil and Gas Journal. October 28, 1968.

4. Graff, R. A. Sulfur Recovery from Petroleum Gases Eliminates an Air-Pollution Problem and Puts a Profit in the Till. The Oil and Gas Journal. November 17, 1960.

5. U.S. Patent No. 2092386. Hans Baehr and Carl Braus, issued May 14, 1940.

6. Giusti, G. P. Petroleum Major Sulfur Source. The Oil and Gas Journal. February 22, 1975.

7. Information Provided by Ford Bacon and Davis Sulfur Recovery Plants. In: Beers, W. D. Characterization of Claus Plant Emissions. EPA-R2-73-188. April 1973.

8. Information Provided by J. F. Pritchard and Co. In: Beers, W. D. Characterization of Claus Plant Emissions. EPA-R2-73-188. April 1973.

9. Beers, W. D. Characterization of Claus Plant Emissions. EPA-R2-73-188. April 1973.

10. Genco, J. M. and S. S. Tam. Characterization of Sulfur Recovery from Refinery Fuel Gas. EPA Contract No. 68-02-0611. June 1974.

11. Pearson, M. J. Developments in Claus Catalysts. Hydrocarbon Processing. February 1973.

Tail Gas Treatment

1. Function - The principal function of tail gas treatment processes is the removal of gaseous sulfur compounds in the effluent of the Claus plant (Process Number 1). These pollutants are generally converted to either elemental sulfur or SO_2 and put back into the main product stream. Sulfur recovery is a secondary function of these processes. A partial list of commercial tail gas treatment processes is provided below.

Beavon
Cleanair
IFP-1
SCOT
Sulfreen
Wellman-Lord
Chiyoda Throughbred 101

2. Input Materials - Specific input requirements for the commercial treatment processes are briefly summarized below. Quantity data is generally not readily available in the open literature.

Beavon: A limited quantity of make-up absorber liquor is required for the Stretford process which is an integral part of the Beavon process (≃ 0.0131 to 0.131 L/sec for a 100 MT/D Claus plant). This solution contains anthraquiamine disulphonic acid, sodium meta vandate, sodium potassium titrate, soda ash, and other compounds.[3] The cobalt molybate catalyst must be replaced every three years.[4]

Cleanair: Detailed technical information is proprietary, however, make-up catalyst and absorber liquor are probably required.

IFP-1: A catalyst composed of mixed alkali salts of an organic acid are used along with a glycol solvent and an ammonium sulfite absorber liquor.[3] Make-up requirements are unknown.

SCOT: Limited quantities of cobalt-molybdenum catalyst and alkanolamine solution are required.[5]

Sulfreen: A catalyst composed of either activated carbon or alumina is required at a rate of 5.6 or 11.0 kg/hr, respectively for a 100 MT/D

Claus plant off-gas.[3] Nitrogen gas is also required (≈ 40 Nm/hr).

Wellman-Lord: 3.7 metric tons of 100% NaOH is required for a 100 metric ton per day Claus plant off-gas.[3]

Chiyoda Throughbred 101: Ferric sulfate catalyst and limestone are required. Limestone quantities are 21 MT/D for a 100 MT/D claus plant.[3]

3. Operating Conditions - The operating conditions of the various tail gas treatment processes are briefly discussed below.

Beavon: Hydrolysis and hydrogeneration are performed at approximately the same temperature and pressure as the Claus plant.[3,4] The Stretford unit operates at approximately 50°C.

Cleanair: No information readily available.

IFP-1: No information readily available.

SCOT: The reactor operates at approximately 300°C and atmospheric pressure.[4] Absorption is done at ambient temperatures following water quenching of the gas stream.

Sulfreen: The reactor operates at 127 to 149°C. Desorption of sulfur is accomplished at 400°C.[3]

Wellman-Lord: Absorption of the SO_2 containing gas stream from the incinerator is done at 38°C[3] and approximately atmospheric pressure.

Chiyoda Throughbred 101: Absorption of an SO_2 containing gas stream from an incinerator is done at 55°C and approximately atmospheric pressure.[3]

4. Utilities - The utility requirements for the various tail gas treatment processes are summarized on the following page. It is readily apparent that there are major differences. The data in the table is based on a 100 metric ton per day Claus plant off-gas. Steam produced in the process is not included in the table.

Approximate Utility Requirements

Process	Electrical power kWh/day	Natural gas MM Btu/day	Water cooling M liters/day	Steam kg/hr	Boiler feed water M liters/day
Beavon[4]	7,200	125	-	-	N.D.
Ceanair	N.D.	N.D.	N.D.	N.D.	N.D.
IFP-1[5]	4,600	-	19,000	2,500	N.D.
SCOT[6]	815	70	16,300	2,900 (50 PSIG)	95
Sulfreen[3]	2,000	15	-	1,770	60
Wellmen-Lord[3]	2,230	3,500	12,900	-	260
Chiyoda Throughbred 103	10,200	55,000	21,200	0	285

5. Waste Streams - The waste streams for the tail gas treatment processes are briefly summarized in the table below. The basis for the quantities shown in the table is a 100 MT/D Claus plant off-gas.

Process	Waste Streams		
	Airborne waste	Aqueous waste	Solid waste
Beavon[3]	0.065 MT/D sulfur compound ($\simeq$26 mg/m^3)	1)Sour water condensate, 250 M liters/day 50 mg/L H_2S 2)Stretford purge solution 4-40 M liters/day (for typical composite - see ref. 3)	Unknown
Cleanair	Gaseous sulfur compound emissions quantities probably similar to Beavon Process	Stretford purge solution, quantities probably similar to Beavon Process	Unknown

Process	Waste Streams		
	Airborne waste	Aqueous waste	Solid waste
IFP-1[3]	0.993 MT/D of sulfur, primarily SO_2 @ 546 mg/m^3	Intermittent catalyst wash waste	Catalyst waste
SCOT[3]	0.08 MT/D sulfur primarily as SO_2 with slight quantities of H_2S; SO_2 concentration ≃ 500 mg/m^3, H_2S concentration 14 mg/m^3	Sour waste condensate ≃ 43 M gas/day, with H_2S @ 30 mg/L	Catalyst waste and small amounts of amine sludge
Sulfreen[3]	1.7 MT/D of sulfur. Primarily as SO_2 at a concentration of 7800 mg/m^3	No major waste	Catalyst waste
Wellman-Lord[3]	0.134 MT/D of sulfur. Primarily as SO_2 at concentration of 550 mg/m^3	1)Sodium sulfate/ sulfite purge, 75 M liters/day 2)Acid water condensate, 115 M liters/day: pH 2.	Unknown
Chiyoda Throughbred 101[3]	0.5 MT/D of sulfur Primarily as SO_2 at concentration of 2000 mg/m^3	Acidic purge stream 50 M liters/day	By-product gypsum, 35 MT/D.

6. EPA Source Classification Codes - None exists.

7. References -

1. Semrau, K. Controlling the Industrial Process Sources of Sulfur Oxides. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfeiffer (ed.). Washington, D.C., Advances in Chemistry Series 139, American Chemical Society, 1975. p. 1-24.

2. Kim, B., Genco, J. M., Oxley, J. and P. Choi. Development of Information for Standards of Performance for the Fossil Fuel Conversion Industry. EPA-450/3-75-029, October 1974.

3. Genco, J. M. and S. S. Tam. Characterization of Sulfur Recovery from Refinery Fuel Gas. EPA Contract No. 68-02-0611. June 1974.

4. Beavon, D. K. and R. N. Fleck. Beavon Sulfur Removal Process for Claus Plant Tail Gas. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfieffer (ed.). Washington, D.C. Advances in Chemistry Series 139, American Chemical Society, 1975. p. 93-99.

5. Swaim, C. D., Jr. The Shell Claus Offgas Treating (SCOT) Process. In: Sulfur Removal and Recovery from Industrial Processes, John B. Pfieffer (ed.). Washington, D. C., Advances in Chemistry Series 139, American Chemical Society, 1975. p. 111-119.

Frasch Process Sulfur Production

1. Function - Almost all of the elemental sulfur produced by the Frasch process is obtained from sulfur bearing porous limestone deposits in the salt dome rocks of Texas and Louisiana. Holes are bored to the bottom of the sulfur bearing strata at depths from 150 to 760 meters.[1,2,3] Three concentric pipes with diameters of 20, 10 and 2.5 cm (8, 4 and 1 inch) within a 25 cm (10 inch) casing are placed in the hole. Hot water is passed down the space between the 20 cm and 10 cm pipes to melt the sulfur from the rocks. The molten sulfur, being heavier than water, sinks to form a pool around the base of the well and is forced up to the surface through the 10 cm pipe by an airlift created by blowing air down the 2.5 cm pipe.[1,2,3] The product sulfur is collected in steam-heated sumps where the air bubbles out.

2. Input Materials - The primary input material is raw sulfur containing less than 0.15 percent ash and less than 0.05 to 1.0 percent hydrocarbons. Large quantities of hot water and air are also required.

3. Operating Parameters - Temperature of the hot water is maintained at about 160 to 165°C. Air is compressed to 28 to 42 kg/cm^2 (400 to 600 pounds per square inch).[1,3] A heating period of 24 hours or longer is required to accumulate a liquid sulfur pool.

4. Utilities - Large quantities of hot water and compressed air are necessary. Water requirements vary from 4 to 50 metric tons per metric ton of sulfur produced.[1] The equivalent heat content of this water is 560,000 to 7,000,000 kcal per metric ton of sulfur.

5. Waste Streams - Blended well water is withdrawn at approximately the same rate as hot water is passed into the sulfur deposits. This waste contains appreciable quantities of hydrogen sulfide and is highly corrosive. At some facilities, the H_2S is stripped with hot air in countercurrent towers. Atmospheric emissions of H_2S result from this operation. H_2S is also evolved from air by air bubbles passing out of the liquid sulfur. The aqueous waste can be treated for hardness and chlorides for reuse or can be discharged.

6. EPA Source Classification Code - None exists.

7. References

1. Shreve, R. N. Sulfur and Sulfuric Acid. In: Chemical Process Industries. New York, McGraw Hill Book Company. 1967.

2. Lowenheim, F. A. and M. K. Moran. Faith, Keyes and Clarks' Industrial Chemicals, fourth edition, Wiley Interscience. 1975.

3. Chemical Technology: An Encyclopedic Treatment. T. J. W. van Thoor (ed.), Barnes and Noble, Inc., 1968.

SULFURIC ACID AND SULFUR DIOXIDE PRODUCTION

The processes necessary for production of sulfuric acid and sulfur dioxide involve one or more of the following; SO_2 formation by SO_2 oxidation, SO_3 absorption, oleum distillation and sulfuric acid concentration. SO_2 formation can be done by a variety of alternative processes including combustion of elemental sulfur, spent acid combustion, roasting of pyrites, or direct recovery for smelter gases. The latter two sources are becoming more important as supplies of elemental sulfur become more expensive. The generalized flowsheets for the processes are shown in Figure 1.

The chemical reactions which are the basis for process design and operating requirements are presented below.

$$S + O_2 \longrightarrow SO_2$$

$$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$$

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

The reversibility of the second reaction has been a major factor affecting total sulfur oxide emissions. During the last 13 years, a variety of processes have been commercialized to achieve greater SO_2 conversion by a two stage SO_3 absorption, and SO_2 conversion technique. This development has both environmental and economical advantages. Other than the development of this dual absorption technology, changes in this industry are comparatively gradual.

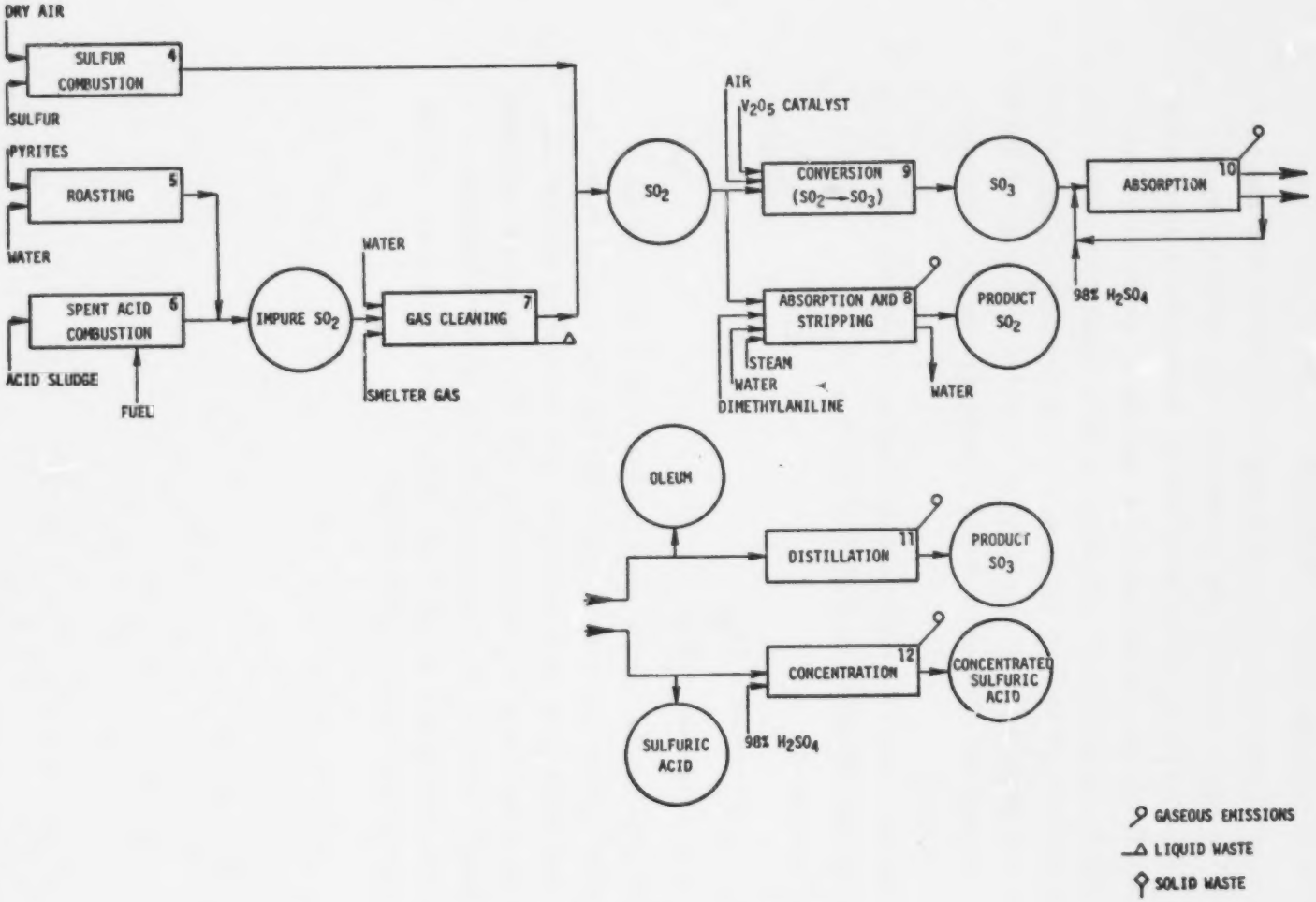

Figure 2. Sulfur oxides production.

SULFUR OXIDES PRODUCTION PROCESS NUMBER 4

Sulfur Combustion

1. Function - Elemental sulfur is burned with dry air to form gaseous sulfur dioxide with a concentration of 8 to 11 mole percent. If the sulfur is in solid form, it is heated to a molten state and settled or filtered to remove ash before it is pumped into the refractor-lined burner. The hot combustion products are passed through waste heat boilers where the gas is cooled and high-pressure steam is generated before it is sent to the absorber or the converter (Process Numbers 8 and 9).

2. Input Materials - The stochiometry of the sulfur oxidation reaction indicates that approximately ½ kilogram of sulfur and 1.2 Nm^3 of air are required per kilogram of SO_2 produced.

3. Operating Parameters - If molten sulfur is to be combusted, the handling equipment must be steam jacketed to maintain the sulfur temperature at 135 to 150°C (275 to 310°F). The temperature of the gas leaving the combustion chamber ranges from 700 to 1000°C.[1] The gas is then cooled to a temperature between 400 and 450°C.[2] The pressure is maintained between 1400 and 4200 kg/m^2 (2 to 6 psig) depending on design, rate of operation, and cleanliness of equipment.

4. Utilities - The sulfur combustion processes involves an exothermic chemical reaction which yields useful steam energy at an estimated rate of 1100 kcal (4360 Btu) per kilogram of SO_2 produced.[1] Utility requirements are minor.

5. Waste Streams - Emissions from combustion chambers are negligible if there are no leaks in heat exchanges. All of the gases formed (SO_2, CO_2, O_2, N_2) are passed to the absorber or to the converter through a closed system.

6. EPA Source Classification Code - None exists.

7. References -

1. Kirk-Othmer. Sulfur Compounds. In: Encyclopedia of Chemical Technology. New York, John Wiley & Sons, Inc., 1969.

2. U.S. Department of Health, Education and Welfare. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. Public Health Service Publications No. 999-AP-13. 1965.

Roasting of Pyrites

1. Function - Pyrite or pyrrhotite is fed at a controlled rate to a fluidized-bed roaster as a slurry with water or as small crushed particles. Combustion air is also fed into the roaster. During roasting at high temperatures the sulfide ores form metallic oxides and sulfur dioxide. The resulting iron oxide by-product is marketed for use in blast furnaces. Flash roasters or multiple-hearth roasters are also in use. The gases formed in this process are then cleaned (Process No. 7).

2. Input Materials - As a rule, maximum allowable carbon content and minimum sulfur content of the pyrite used for acid production are 8 percent and 42 percent, respectively. Table 8 gives typical feed requirements for the roasting operation.[1]

Table 8. TYPICAL FEED FOR PYRITE ROASTING

Material	Quantity
Pyrite feed	1 ton
Sulfur content	46 percent
Carbon content	5 percent
Water	0 liters

3. Operating Parameters - The roasting temperature is controlled by water sprays or cooling tubes located in the fluidized bed. The SO_2-containing gases leave the roaster at 800 to 900°C. Air for oxidation and for fluidizing the bed is drawn from the atmosphere by a blower.[2]

4. Utilities - Roasting of pyrites requires the following per metric ton of feed ore: 115 kWh of electrical energy, 20,000 liters of cooling water. Roasting also produces about 250 kWh of electrical energy per ton of pyrite charged.

5. Waste Streams - Since the entire roaster gas product stream is passed to the absorption or conversion process, the atmospheric emissions are negligible except for leaks which have not been quantified.

6. EPA Source Classification Code - None exists.

7. References -

1. Pollution Control and By-Product Sulfur Too. Engineering and Mining Journal. June 1968.

2. Chemical Construction Corporation. Sulfuric Acid from Pyrite or Pyrrhotite. In: Modern Contact Sulfuric Acid Processes. Bulletin No. 116. New York.

SULFUR OXIDES PRODUCTION PROCESS NUMBER 6

Spent Acid Combustion

1. Function - Spent acid, sludge, or other feed is pumped to a combustion furnace along with air where it is decomposed at a high temperature to produce sulfur dioxide and small amounts of carbon dioxide and water. The resulting combustion gas is cooled in waste heat boilers and then cleaned (Process Number 7).

2. Input Materials - The spent acid usually contains about 90 percent sulfuric acid, 4 to 5 percent water, and 5 to 6 percent hydrocarbons.[1,2] Some quantities of hydrogen sulfide or sulfur are also burned when make-up acid is required.[1]

3. Operating Parameters - Furnace temperature is maintained at about 1000 to 1100°C. The gas is cooled to a temperature of 370°C.[1]

4. Utilities - The hydrocarbons in the spend acid provide part of the fuel. Additional heat is provided by burning fuel oil or gas in the presence of air. The fuel requirements increase with increasing water content of the feed material.

5. Waste Streams - Emissions are negligible because the entire product formed from burning spent acid is sent to a gas cleaning unit.

6. EPA Source Classification Code - None exists.

7. References -

1. Chemical Construction Corporation. Sulfuric Acid from Spent Acids. In: Modern Contact Sulfuric Acid Processes. Bulletin No. 116. New York.

2. Shreve, R. N. Sulfur and Sulfuric Acid. In: Chemical Process Industries. New York, McGraw Hill Book Company. 1967.

Gas Cleaning

1. Function - Because off-gases from nonferrous smelting operations and spent acid combustion contain considerable amounts of particulate material, they are scrubbed with weak acid. The gas is then cooled and passed through an electrostatic precipitator for removal of dust and sulfuric acid mist. The cleaned gas is dried with 93 percent acid in a drying tower before it enters a converter in the acid plant.

2. Input Materials - The sulfur dioxide content of gases from smelting operations ranges from 4 to 14 percent.[1] Weak acid (10% H_2SO_4) is also required for the scrubbing liquor.

3. Operating Parameters - In the drying tower smelting gases are cooled from 70°C to 37°C to reduce the moisture content.[2] Temperature of roasting gases is reduced from 900°C to 350°C.[3]

4. Utilities - Table 9 gives typical utility requirements for a smelting gas purification process and contact sulfuric acid plant.[2]

5. Waste Streams - Waste water results from this process. This water is treated to remove particulate material. Quantitative waste water data are not readily available.

The exit gases are contained and processed further to recover the sulfur, thus eliminating all but fugitive emissions.

Table 9. TYPICAL UTILITY REQUIREMENTS OF SMELTER GAS PURIFICATION AND CONTACT ACID PRODUCTION PLANTS (FOR PROCESS 6 AND 9 TO 11)
(Basis: 1 ton of H_2SO_4 produced)

Utility	Quantity
Electric power for all electric motor drives	52 kWh
Water for gas cooling at 29°C	15,000 liters
Water for acid cooling	40,000 liters

6. EPA Source Classification Code - None exists.

7. References

1. Rinckhoff, J. B. Sulfuric Acid Plants for Copper Converter Gas. In: Sulfur Removal and Recovery from Industrial Processes. John B. Pfeiffer (ed.), Washington, D.C., Advances in Chemistry 139, American Chemical Society, 1975. p. 48-59.

2. Semrau, K. T. Control of Sulfur Oxide Emissions from Primary Copper, Lead, and Zinc Smelters--A Review. (For Presentation at the 63rd Annual Meeting of the Air Pollution Control Association. Missouri. June 14-18, 1970).

3. Chemical Construction Corporation. Sulfuric Acid from Pyrite or Pyrrhotite. In: Modern Contact Sulfuric Acid Processes. Bulletin No. 116. New York.

Absorption and Stripping

1. Function - To make product grade SO_2, the cooled gas from the combustion chamber is contacted and absorbed by water in a packed tower absorber.[1] When the SO_2 is obtained from other sources, such as smelter gases, the SO_2 is cleaned and then is absorbed by anhydrous dimethylaniline in a bubble cap tower. The cool, absorbed liquor is stripped by heating with low-pressure steam to produce a gaseous mixture of sulfur dioxide and water vapor which is dried with sulfuric acid and finally compressed and liquified. The final product, liquid SO_2, contains less than 50 ppm of water. The commercial grade of the liquid product is 99.98 percent pure sulfur dioxide.

2. Input Materials - From 50 to 100 tons of water are required per ton of sulfur dioxide produced. Consumption of dimethylaniline is about 0.5 kg/ton of SO_2 produced.[2]

3. Operating Parameters - The absorption is carried out at approximately atmospheric pressure.

4. Utilities - Not available.

5. Waste Streams - Gaseous emissions from this process are composed mainly of water vapor. Exit gases from packed towers contain from 0.02 to 0.1 percent sulfur dioxide.[2] The liquid waste from the stripping process contains about 0.01 percent SO_2 by weight.[2]

6. EPA Source Classification Code - None exists.

7. References

1. Chemical Technology: An Encyclopedic Treatment. T. J. W. van Thoor (ed.), Barnes and Noble, Inc., 1968.

2. Kirk-Othmer. Sulfur Compounds. In: Encyclopedia of Chemical Technology. New York, John Wiley and Sons, Inc. 1969.

Converter

1. Function - Cooled sulfur dioxide gas passes through a converter and is converted to sulfur trioxide in the presence of excess oxygen and vanadium pentoxide catalyst. Converters usually incorporate two, three or four stages. Various types of gas coolers are used between converter stages. The converter exit gases are cooled before further processing in the absorption tower.

Most new plants operate with a dual absorption system where partially converted gas is passed through an intermediate absorption tower, back to a converter and then to the final absorber. This system achieves SO_2 to SO_3 conversion efficiencies greater than 99.5 percent.

2. Input Materials - SO_2 content of gases entering the converter range from 6.0 to 12 percent, depending on the source. Efficiency of the conversion to SO_3 is between 95 and 98 percent for 3- or 4-stage converters. If the sulfur dioxide is produced from a source other than elemental sulfur, it may also contain arsenic, chlorine, and fluorine.[1]

Vanadium pentoxide catalyst requirements are listed below:

Number of stages	Conversion efficiency, %	Catalyst required, liters/day/ton of acid
2	94	120
3	96	145
4	98	165

3. Operating Parameters - Inlet feed gas temperature normally ranges from 425 to 450°C. The processes operate at approximately atmospheric pressure. The gas is cooled between converter stages and finally exits between 230 and 260°C.[1]

4. Utilities - No utilities are required. Heat released from this process may be recovered as steam.

5. Waste Streams - Since all the converter gases are passed to the absorption tower, there are only fugitive emissions. Disposal of catalyst waste is required.

6. EPA Source Classification Code - None exists.

7. References

1. Shreve, R. N. Sulfur and Sulfuric Acid. In: Chemical Process Industries. New York, McGraw Hill Book Company. 1967.

2. Personal communication with Mr. Bruce Varner. Emission Standards and Engineering Division. Environmental Protection Agency. Research Triangle Park, North Carolina.

Absorption Tower

1. Function - The cooled effluent from the converter is passed into an absorption tower for the production of sulfuric acid or an oleum tower for the production of oleum. Sulfuric acid (98 to 99 percent) is circulated in the absorption tower. The sulfur trioxide combines with the water in the acid to form more acid at nearly 100 percent absorption efficiency. If oleum (sulfur trioxide dissolved in 100 percent sulfuric acid) is to be produced, the sulfur trioxide stream from the converter is cooled further before it is passed through an absorber which is then called an oleum tower. In the oleum tower some of the SO_3 is absorbed in the presence of recirculating acid. The equipment involved in the absorption and oleum towers is similar with differences in the methods of operation. Recirculation in the oleum tower allows more absorption of sulfur trioxide to take place. The effluent gases from the tower are passed through another absorber for recovery of the residual sulfur trioxide.

2. Input Materials - The gases from the converter are the main input material. Concentration of SO_3 is in the 4 to 12 percent range. The entering gases also contain unconverted SO_2, traces of moisture and carbon dioxide. The moisture and CO_2 incomplete drying of combustion air and burning of hydrocarbons in the sulfur.

3. Operating Conditions - The absorption tower inlet gas temperature is between 230 and 260°C and less than 225°C for an oleum tower.[1]

4. Utilities - Not available.

5. Waste Streams - Waste gas from the absorber is the major source of emissions from contact sulfuric acid plants. The effluent gas contains some unreacted sulfur dioxide, unabsorbed sulfur trioxide, and sulfuric acid mist.[1] Uncontrolled emissions from an absorber vary as shown in Table 10 and average about 30 kilograms of SO_2, 1.5 to 6 kilograms of acid mist, and 0.1 kilograms of SO_3 per ton of sulfuric acid produced.[2] The gases may also contain nitrogen oxides which result from nitrogen compounds in the raw materials used, spent acid being the feedstock

Table 10. CHARACTERISTICS OF TAIL GAS EMISSIONS FROM CONVENTIONAL SULFURIC ACID PLANTS

Feedstock	Exit gas flow,[a] m^3/ton of acid (as 100% H_2SO_4)		SO_2 content ppm		SO_2 emissions, kg/ton of acid		Acid mist,[b] mg/m^3	
	3-stage conversion	4-stage conversion	3-stage conversion	4-stage conversion	3-stage conversion	4-stage conversion	99% acid	Oleum
Sulfur	2870	2840	3000 to 5000	1500 to 4000	22 to 37	11 to 29	70 to 700	180 to 1800
H_2S	3120	3090	3000 to 5000	1500 to 4000	24 to 40	12 to 32	70 to 700	180 to 1800
Pyrites	3400	3370	2500 to 5000	1500 to 4000	22 to 44	13 to 35	70 to 700	180 to 1800
Acid sludge	3710	3670	2500 to 5000	1500 to 4000	24 to 48	14 to 38	70 to 700	180 to 1800
Copper converter gas	5990	5740	2000 to 10000	2000 to 7000	31 to 156	30 to 104	70 to 700	180 to 1800
Roaster gas	4520	4460	2000 to 5000	1000 to 4000	23 to 46	12 to 46	70 to 700	180 to 1800

[a]These are maximum values. Flow will vary with plant design and excess air used.

[b]Number of conversion stages does not effect mist emissions. Plants using high purity sulfur yield lower mist emissions. These are uncontrolled mist emissions. Divide by approximately 250 to convert to kg/metric ton.

most likely to produce them.[2] For a given mass emission rate, pollutant concentrations are a function of the volume of air fed to the process. The air volume in turn depends on the SO_2 concentration in the gas stream fed to the converters. The conversion efficiency and thereby the emissions are affected by the number of catalyst stages, the amount of catalyst used, the temperature, and the concentrations of the reactants and sulfur dioxide. Table 11 gives emission factors for sulfuric acid plants with different rates of conversion of SO_2 to SO_3.[4] Concentration of the acid mist emissions in the stack gas range from 70 to 700 milligrams per cubic meter for a plant producing no oleum and from 180 to 1800 milligrams per cubic meter for an oleum plant.[5] The reported values for unabsorbed sulfur trioxide range from less than 20 to 1700 milligrams per cubic meter.[1] Mesh mist eliminators or electrostatic precipitators are used to reduce mist emissions.

Table 11. EMISSION FACTORS FOR SULFURIC ACID PLANTS

Conversion of SO_2 to SO_3, %	SO_2 emissions	
	lb/ton of 100% H_2SO_4	kg/MT of 100% H_2SO_4
93	96	48.0
94	82	41.0
95	70	35.0
96	55	27.5
97	40	20.5
98	27	13.0
99	14	7.0
99.5	7	3.5
99.7	4	2.0
100	0	0.0

Mist particles range from 0.3 to 5.0 microns in diameter.[2] Table 12 shows a particle size distribution for sulfuric acid mist at plants producing acid, 20 percent oleum, and 32 percent oleum.[5]

Table 12. PARTICLE SIZE DISTRIBUTIONS IN SELECTED SULFURIC ACID PLANT ABSORBER EFFLUENTS

Particle diameter, microns	Cumulative weight percent smaller than		
	Acid production only	20% oleum production	32% oleum production
0.2		0.4	3.6
0.4		2	16
0.6	1	4.8	30
0.8	7	8	42
1.0	12	11.6	53
1.5	21	48	86.5
2.0	40	84.5	97

Exit plumes from oleum-producing sulfuric acid plants usually are more highly visible than those of acid-producing plants. The visibility is more a function of the extremely fine particle size than of total mist concentration.[6]

Dual absorption will substantially reduce the SO_2 content of the exit gases, but does not affect mist emissions.

6. EPA Source Classification Code - The following SCC codes apply to entire contact sulfuric acid plants.

3-01-023-01 for 99.7% conversion of SO_2 to SO_3
3-01-023-04 for 99.5% conversion of SO_2 to SO_3
3-01-023-06 for 99.0% conversion of SO_2 to SO_3
3-01-023-08 for 98.0% conversion of SO_2 to SO_3
3-01-023-10 for 97.0% conversion of SO_2 to SO_3
3-01-023-12 for 96.0% conversion of SO_2 to SO_3
3-01-023-14 for 95.0% conversion of SO_2 to SO_3
3-01-023-16 for 94.0% conversion of SO_2 to SO_3
3-01-023-18 for 93.0% conversion of SO_2 to SO_3

7. References

1. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. U.S. Department of Health, Education and Welfare. Public Health Service Publication No. 999-AP-13. Cincinnati, 1965.

2. Guidelines for Limitation of Contact Sulfuric Acid Plant Emissions. Office of Air Pollution Control Publication No. APTD-0602, Environmental Protection Agency, Research Triangle Park, North Carolina. January 1971.

3. Engineering Analysis of Emissions Control Technology for Sulfuric Acid Manufacturing Processes. Chemical Construction Corporation. NTIS Publication No. PB190393.

4. Compilation of Air Pollution Emission Factors. EPA Publication No. AP-42. Environmental Protection Agency. Research Triangle Park, North Carolina. April 1973.

5. Varner, B. A., Bunyard, F. L. and G. B. Crane. State Guidelines for Standards of Performance for Existing Sulfuric Acid Plants. Environmental Protection Agency, Research Triangle Park, North Carolina. January 1975.

6. Brink, J. A., Jr., Burggrable, W. F. and L. E. Greenwell. Mist Eliminators for Sulfuric Acid Plants. Chemical Engineering Progress. November 1968.

SULFUR OXIDES PRODUCTION PROCESS NUMBER 11

Distillation

1. Function - Sulfur trioxide product is produced by heating 20 percent or stronger oleum to the boiling point in either an indirect-fired vessel or a high-pressure steam-heated vessel and distilling sulfur trioxide. Entrained acid mist is removed with mist filters or similar equipment. The distilled product is then cooled and condensed to liquid. Usually some stabilizer such as a mixture of several boron compounds and dimethyl sulfate is added to eliminate any traces of moisture. The final liquid sulfur trioxide product is stored and maintained between the freezing point (34°C) and the boiling point (45°C).[1] The distallate residue is returned to absorption towers as 10 percent oleum.
2. Input Materials - 20 percent or stronger oleum is used. The quantity of stabilizer used is very small with a resulting boron content of between 0.0005 to 0.1 weight percent expressed as boron oxide.
3. Operating Conditions - Distillation is carried out at atmospheric pressure.
4. Utilities - Heat is required to bring oleum to its boiling point.
5. Waste Streams - Vent gases are generally scrubbed with strong or absorbing strength (98-99.5 percent) sulfuric acid before discharge. Quantitative emission data are not available.
6. EPA Source Classification Code - None exists.
7. References

1. Kirk-Othmer. Encyclopedia of Chemical Technology. New York, John Wiley & Sons, Inc. 1966.

Acid Concentrator

1. Function - Spent sulfuric acid may be concentrated in one of the two types of concentrators: a vacuum or a drum concentrator. The vacuum concentrator operates under high vacuum with heat applied indirectly; the drum concentrator operates with heat applied directly in the form of combustion gases.[1,2]

In the vacuum concentrator, the hot acid is concentrated by evaporation in a flash chamber. The vapors consisting of water and some H_2SO_4 are liquified in a condenser. The drum concentrator, the more popular of the two for plants with large capacities and high acid concentrations, provides a countercurrent contact of a hot gas mixture and the weak acid. The number of drums determines the number of stages. H_2SO_4 vapor formed in a high concentration stage is partly condensed in the following stages.[3] The product acid is passed through an acid cooler before being sent to storage.[1]

2. Input Materials - Inlet acid concentrations range from 65 to 93 percent.

3. Operating Conditions - Vacuum concentrators operate at 69 to 75 centimeters Hg.[2]

4. Utilities - Table 13 gives a typical utility requirement of a drum-type sulfuric acid concentrator.[1]

Table 13. UTILITY REQUIREMENTS OF A DRUM-TYPE SULFURIC ACID CONCENTRATOR

(Basis: 1 ton of sulfuric acid concentrate from 65 to 93 percent acid)

Utility	Quantity
Fuel	554,000 kilocalories
Electric power	36 kilowatt-hours
Cooling water	5,000 liters

5. Waste Streams - Vacuum concentrators yield negligible emissions. Emissions from drum concentrators contain acid mist. Since the main function of concentrators is to remove water from the acid, the exit gases contain large amounts of water vapor which condense to form a visible fog. Emissions also contain acid mist and negligible quantities of SO_2. Before being discharged to the atmosphere, the exit gas is treated in scrubbers.[3] Table 14 gives emissions from acid drum concentrators with different operating capacities.[4]

Table 14. EMISSIONS FROM ACID DRUM CONCENTRATORS[4]

Operating rate, percent of capacity	55	73	100
Acid mist concentration mg/m^3	82	110	150
Acid mist emission quantity metric ton/day	7034	2401	2334
Particle size wt % < 3 microns	85	86	57[a]

[a]At maximum capacity more large particles are entrained.

6. EPA Source Classification Code - None exists.

7. References

1. [illegible] Corporation. Sulfuric Acid from Pyrite [illegible]dern Contact Sulfuric Acid Processes. [illegible]York.

2. Shreve, R. N. Sulfur and Sulfuric Acid. In: Chemical Process Industries. New York, McGraw Hill Book Company. 1967.

3. Chemical Construction Corporation. Engineering Analysis of Emissions Control Technology for Sulfuric Acid Manufacturing Processes. PB 190 393. New York. March 1970.

4. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. Public Health Service Publication No. 999-AP-13. U.S. Department of Health, Education and Welfare. Cincinnati, 1965.

APPENDIX A

COMPANIES AND THEIR PRODUCTS

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Table A-1. PRODUCERS OF ELEMENTAL SULFUR, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Alaska Interstate Co.			
Anlin Co. of Illinois, subsid.	Wood River, Ill.	54	Refinery
Anlin Co. of New Jersey, subsid.	Perth Amboy, N.J.	18	Refinery
Allied Chem. Corp.			
Indust. Chems. Div.	Elizabeth, N.J.		
Amarillo Oil Co.	Goldsmith, Tex.	20	Refinery. May be closed.
Amerada Hess Corp.	Port Reading, N.J.	4	Natural gas
	Purvis, Miss.	15	Refinery
		11	Refinery
American Cyanamid Co.			
Organic Chems. Div.	Bound Brook, N.J.	n.a.	Carbon bisulfide plant effluent
American Petrofina, Inc.			
American Petrofina Co. of Texas, subsid.	Mt. Pleasant, Tex.	4	Natural gas
	Port Arthur, Tex.	20	Refinery
Cosden Oil & Chem. Co., subsid.	Big Spring, Tex.	5	Refinery
American Smelting and Refining Co.	El Paso, Tex.	n.a.	Smelter gases; pilot plant
Arkansas Louisiana Gas Co.			
Arkla Chem. Corp., subsid.	Magnolia, Ark.	7	Natural gas may be closed
Ashland Oil, Inc.			
Ashland Chem. Co., div.			
Petrochems. Div.	Canton, Ohio	n.a.	
	North Tonawanda, N.Y.	16	Refinery
Northwestern Refining Co., subsid.	St. Paul Park, Minn.	6	Refinery
Atlantic Richfield Co	Artesia, N.M.	5	Natural gas
	Fashing, Tex.	3	Natural gas
	Fort Stockton, Tex.	152	Frasch
ARCO Chem. Co., div.	Cherry Point, Wash.	41	Refinery
	East Chicago, Ind.	n.a.	Refinery
	Houston, Tex.	31	Refinery
	Philadelphia, Pa.	36	Refinery. Some sulfur values from refinery H_2S are recovered directly as acid at Philadelphia
	Wilmington, Calif.	25	Refinery
Bethlehem Steel Corp	Burns Harbor, Ind.	n.a.	Coke oven gas
	Lackawanna, N.Y.	n.a.	Coke oven gas
	Sparrows Point, Md.	14	Coke oven gas
The Charter Co.			
Charter Oil Co., subsid.			
Charter International Oil Co., subsid.	Houston, Tex.	15	Refinery
Chem-Gas Products Co.	Worland, Wyo.	7	Natural gas
Cities Service Co., Inc.			
Columbian Div.			
North American Petroleum Group	Seagraves, Tex.	8	Natural gas
	Cochran County, Tex.	2	Natural gas
	Dawson County, Tex.	2	Natural gas
	Lake Charles, La.	16	Refinery
	Milnesand, N.M.	8	Natural gas
	Myrtle Springs, Tex.	122	Natural gas
Climax Chem. Co.	Monument, N.M.	13	Natural gas; may be closed or may use as direct feed for sulfuric acid plant
Coastal States Gas Corp.			
Coastal States Marketing, Inc., subsid.	Corpus Christi, Tex.	25	Natural gas
Continental Oil Co.			
Douglas Oil Co., subsid.	Paramount, Calif.	31	Refinery
Diamond Shamrock Corp.			
Diamond Shamrock Oil and Gas Co.	Dumas, Tex.	5	Natural gas and crude oil
Dorchester Gas Corp.			
Dorchester Gas Producing Co., subsid.	Reagan County, Tex.	2	Natural gas
El Paso Natural Gas Co.			
El Paso Products Co., subsid.			
Odessa Natural Gasoline Co., subsid.	Odessa, Tex.	10	Natural gas
Exxon Corp.			
Exxon Co., U.S.A.	Baton Rouge, La.	71	Refinery
	Baytown, Tex.	n.a	Refinery
	Benicia, Calif.	51	Refinery
	Flomaton, Ala.	51	Natural gas
	Jay, Fla.	25	Natural gas
	Jourdanton, Tex.	6	Refinery
	Linden, N.J.	51	Refinery

[1] Capacity expressed in metric tons.

Table A-1(continued). PRODUCERS OF ELEMENTAL SULFUR, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Farmers Union Central Exchange Inc.	Laurel, Mont.	5	Refinery
Farmland Indust., Inc.			
CRA, Inc., subsid.	Coffeyville, Kans.	2	Refinery
Freeport Minerals Co.			
Freeport Sulphur Co., div.	Chauvin, La.	610	Frasch
	Grand Isle, La.	1524	Frasch
	Port Sulphur, La.	1331	Frasch
	Venice, La.	833	Frasch
Getty Oil Co.	Delaware City, Del.	124	Refinery - may be expanded
	Scoggins, Tex.	66	Natural gas
	Teas Field, Tex.	41	Natural gas
The Goodyear Tire & Rubber Co.			
Chem. Div.	Akron, Ohio	n.a.	By-product sulfur dioxide
Gulf Oil Corp.			
Gulf Oil Chems. Co., div.			
Petrochems. Div.	Alliance, La.	n.a.	
	Philadelphia, Pa.	16	Refinery
	Port Arthur, Tex.	53	Refinery
	Santa Fe Springs, Calif.	11	Refinery
	Toledo, Ohio	n.a.	
Warren Petroleum Corp., div.	Campbellton, Tex.	15	Natural gas
	Como, Tex.	36	Natural gas
	Sand Hills, Tex.	12	Natural gas
	Waddell, Tex.	31	Natural gas
Husky Oil Co.	Cody, Wyo.	17	Natural gas
Intratex Gas Co.	Pecos, Tex.	6	Natural gas
Kerr-McGee Corp.			
Kerr-McGee Chem. Corp., subsid.	Indian Basin, N.M.	10	Natural gas
Koch Indust., Inc.			
Koch Refining Co., subsid.	Pine Bend, Minn.	47	Refinery
Marathon Oil Co.	Artesia, N.M.	13	Natural gas
	Detroit, Mich.	41	Refinery
	Iraan, Tex.	5	Natural gas
	Robinson, Ill.	15	Refinery
Mobil Oil Corp.			
North American Div.	Coyanosa, Tex.	5	Natural gas, may be closed
	Joliet, Ill.	102	Refinery
	Paulsboro, N.J.	25	Refinery
	Torrance, Calif.	140	Refinery
Monsanto Co.			
Monsanto Indust. Chems. Co.	Avon, Calif.	56	Refinery
Montana Sulphur & Chem. Co.	East Billings, Mont.	36	Refinery
National Steel Corp.			
Weirton Steel Div.	Weirton, W.Va.	n.a.	
Northern Natural Gas Co.	Hobbs, N.M.	5	Natural gas
Occidental Petroleum Corp.			
Occidental Chem. Co., subsid.			
Jefferson Lake Sulphur Co., div.	Long Point Dome, Tex.	330	Frasch
The Oil Shale Corp.			
Lion Oil Co., subsid.	El Dorado, Ark.	5	Refinery
Olin Corp.			
Indust. Products and Services Div.	Beaumont, Tex.	15	Refinery
Pasco, Inc.	Sinclair, Wyo.	9	Natural gas
Pennzoil Co.			
Duval Corp., subsid.	Pecos, Tex.	1524	Expandable to 2500
Phillips Petroleum Co.	Artesia, N.M.	4	Natural gas
	Borger, Tex.	15	Refinery
	Crane, Tex.	35	Natural gas
	Goldsmith, Tex.	30	Natural gas
	Kansas City, Kans.	13	Refinery
	Sweeny, Tex.	10	Refinery
	Madill, Okla.	4	Natural gas
Pioneer Natural Gas Co.	Santa Fe Springs, Calif.	7	Refinery
Powerine Oil Co.			
Shell Chem. Co.			
Petrochems. Div.	Brandon, Miss.	457	Natural gas
	Bryan's Mill, Tex.	66	Natural gas
	Deer Park, Tex.	51	Refinery
	Martinez, Calif.	15	Refinery
	Norco, La.	23	Refinery
	Persons, Tex.	8	Natural gas
	Thomasville, Miss.	457	Sour gas
The Signal Companies, Inc.			
Signal Oil and Gas Co., subsid.	Tioga, N.D.	51	Natural gas

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Table A-1(continued). PRODUCERS OF ELEMENTAL SULFUR, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Skelly Oil Co.	El Dorado, Kans.	16	Refinery
Standard Oil Co. of California	El Segundo, Calif.	165	Refinery
Standard Oil Co. (Indiana)			
Amoco Oil Co., subsid.	Sugar Creek, Mo.	36	Refinery
	Whiting, Ind.	66	Refinery
	Yorktown, Va.	23	Refinery
Amoco Production Co., subsid.	Andrews, Tex.	4	Natural gas
	Artesia, N.M.	8	Natural gas
	Edgewood, Tex.	214	Natural gas
	Frankel City, Tex.	5	Natural gas
	Goldsmith, Tex.	7	Natural gas
	Powell, Wyo.	27	Natural gas
	Riverton, Wyo.	26	Natural gas
	Sundown, Tex.	18	Natural gas
	Yantis, Tex.	30	Natural gas
The Standard Oil Co. (Ohio)			
BP Oil Corp., subsid.	Marcus Hook, Pa.	n.a.	Refinery
Stauffer Chem. Co.			
Indust. Chem. Div.	Baytown, Tex.	36	Refinery
Specialty Chem. Div.	Freeport, Tex.	n.a.	
Sun Oil Co.			
Sun Oil Co. of Pennsylvania, subsid.	Jay, Fla.	13	Natural gas
	Marcus Hook, Pa.	15	Refinery
	Toledo, Ohio	10	Refinery
Puerto Rico Sun Oil Co., subsid.			
Yabucoa Sun Oil Co., subsid.	Yabucoa, P.R.	20	Refinery
Texaco Inc.	Andrews County, Tex.	2	Natural gas
	Ector County, Tex.	<1	Natural gas
	Eddy County, N.M.	<1	Natural gas
	Franklin County, Tex.	15	Natural gas
	Hockley County, Tex.	3	Natural gas
	Hopkins County, Tex.	2	Natural gas
	Port Arthur, Tex.	10	Refinery
	Vermillion Parish, La.	<1	Natural gas
	Westville, N.J.	1	Refinery
	Wilmington, Calif.	31	Refinery
	Wood County, Tex.	<1	Natural gas
TXL Oil Corp., subsid.	Lignite, N.D.	2	Natural gas
Texas American Oil Corp.			
Texas American Sulphur Co., subsid.	Sand Hills, Tex.	6	Natural gas
Texasgulf, Inc.			
Agricultural Div.	Beaumont, Tex.	660	Frasch
	Bullycamp Dome, La.	305	Frasch
	Hamshire, Tex.	178	Frasch
	Liberty, Tex.	253	Frasch
	Newgulf, Tex.	1626	Frasch
Total Leonard, Inc.	Alma, Mich.	4	Refinery
Trans-Jeff Chem. Corp.	Tilden, Tex.	30	Natural gas
Union Carbide Corp.			
Union Carbide Caribe, Inc., subsid.	Penuelas, P.R.	n.a.	
Union Oil Co. of California	Arroyo Grande, Calif.	19	Refinery
	Lemont, Ill.	11	Refinery
	Rodeo, Calif.	19	Refinery
	San Juan County, Utah	5	Natural gas
	Wilmington, Calif.	41	Refinery
Union Pacific Corp.			
Champlin Petroleum Co., subsid.	Wilmington, Calif.	10	Refinery
United States Steel Corp.			
USS Chems., div.	Clairton, Pa.	15	Coke oven gas
	TOTAL	>13366	

These listings include only those plants designed to produce or recover new sulfur in elemental form. Excluded are a number of facilities that recover new sulfur values directly as sulfuric acid or SO_2–without intermediate isolation of the sulfur in elemental form. This includes recovery directly as acid from H_2S (from refinery gases, sour natural gas, and/or coke-oven gas) and recovery directly as acid or SO_2 from smelter gases and pyrites. Also excluded are companies that mine pyrites and low-to-medium grade sulfur ores.

Source: Compiled in association with the *Chemical Economics Handbook*.

Table A-2. PRODUCERS OF SULFUR DIOXIDE, THEIR ANNUAL CAPACITY[1]

Company	Location	Annual capacity 1000 of tons	Remarks
American Cyanamid Co.			
Organic Chems. Div.	Bound Brook, N.J.	1	
American Smelting and Refining Co.	Tacoma, Wash.	60	
The Ansul Co.			
Chem. Div.	Marinette, Wisc.	14	
Cities Service Co., Inc.			
North American Chems. and Metals Group			
Indust. Chems. Div.	Copperhill, Tenn.	45	
Essex Chem. Corp.			
Chems. Div.	Newark, N.J.	14	
Olin Corp.			
Indust. Products and Services Div.	Paulsboro, N.J.	na	Captive
Rohm and Haas Co.	Bristol, Pa.	9	All captive
Scott Paper Co.			
Packaged Products Div.	Anacortes, Wash.	na	Captive
	Everett, Wash.	na	Captive
	Oconto Falls, Wisc.	na	Captive
	Winslow, Me.	na	Captive
Stauffer Chem. Co.			
Indust. Chem. Div.	Baton Rouge, La.	12	
	Hammond, Ind.	19	
Virginia Chems. Inc.			
Indust. Chems. Dept.	Portsmouth, Va.	40	
	TOTAL	200	

Sources: Oil, Paint and Drug Reporter, December 21, 1970; Sulfur, March/April 1971; and correspondence.

Table A-3. PRODUCERS OF SULFUR TRIOXIDE[1]

Company	Location
Allied Chem. Corp. Indust. Chems. Div.	Buffalo, N.Y. Chicago, Ill. East St. Louis, Ill. El Segundo, Calif.
Cities Service Co., Inc. North American Chems. and Metals Group Indust. Chems. Div	Copperhill, Tenn.
E. I. du Pont de Nemours & Co., Inc. Indust. Chems. Dept	East Chicago, Ind. Linden, N.J. North Bend, Ohio
Stauffer Chem. Co. Indust. Chem. Div.	Dominguez, Calif. Hammond, Ind. Manchester, Tex.

Table A-4. PRODUCERS OF SULFURIC ACID, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Alaska Interstate Co.			
Anlin Co. of Illinois, subsid.	Wood River, Ill.	78	Spent acids
Allied Chem. Corp.			
Indust. Chems. Div.	Anacortes, Wash.	73	Elemental; sludge; hydrogen sulfide
	Baton Rouge, La.	91	Elemental; sludge
	Buffalo, N.Y.	177	Elemental; sludge; hydrogen sulfide
	Chicago, Ill.	145	Elemental; sludge
	Cleveland, Ohio	118	Elemental
	East St. Louis, Ill.	172	Elemental
	Elizabeth, N.J.	181	Elemental; sludge
	Front Royal, Va.	145	Elemental
	Geismar, La.	454	Elemental
	Hopewell, Va.	181	Elemental; may be expanded.
	Newell, Pa.	227	Sludge; pyrites
	Nitro, W.Va.	127	Elemental
	North Claymont, Del.	318	Sludge; pyrites
	Pittsburg, Calif.	127	Elemental; sludge
	Richmond, Calif.	200	Sludge; hydrogen sulfide
American Cyanamid Co.			
Indust. Chems. and Plastics Div.	Hamilton, Ohio	82	Elemental
	Joliet, Ill.	45	Elemental
	Kalamazoo, Mich.	23	Elemental
	Linden, N.J.	218	Elemental
	New Orleans, La.	50	Elemental
	Savannah, Ga.	204	Elemental
Organic Chems. Div.	Bound Brook, N.J.	59	Elemental
American Metal Climax, Inc.			
AMAX Lead & Zinc, Inc., div.	Sauget, Ill.	132	Smelter gases
AMAX Lead Co. of Missouri, subsid.			
Amax-Homestake Lead Tollers	Boss, Mo.	50	Smelter gases
American Smelting and Refining Co.	Columbus, Ohio	59	Smelter gases
	Corpus Christi, Tex.	64	Smelter gases
	El Paso, Tex.	154	Smelter gases
	Hayden, Ariz.	300	Smelter gases
	Tacoma, Wash.	59	Smelter gases
The Anaconda Co.			
Primary Metals Div.	Anaconda, Mont.	313	Smelter gases
	Weed Heights, Nev.	127	Elemental; sulfur ore; smelter gases - May be closed
Arkansas Louisiana Gas Co.			
Arkla Chem. Corp., subsid.	Helena, Ark.	136	Elemental
Baker Indust. Corp.			
Agricultural Products Corp., subsid.	Conda, Idaho	272	Elemental
National Phosphate Corp., subsid.	Marseilles, Ill.	231	Elemental
	Taft, La.	463	Elemental
Bethlehem Steel Corp.	Sparrows Point, Md.	82	Pyrites; hydrogen sulfide
Borden Inc.			
Borden Chem. Div.	Norfolk, Va.	73	Elemental
Smith-Douglass	Piney Point, Fla.	445	Elemental
	Streator, Ill.	36	Elemental
CF Indust., Inc.			
Bartow Phosphate Complex	Bartow, Fla.	1542	Elemental
Plant City Phosphate Complex	Plant City, Fla.	544	Elemental
Chem. Producers Co.	El Paso, Tex.	77	Elemental; sludge
Cities Service Co., Inc.			
Columbian Div.	Monmouth Junction, N.J.	32	
North American Chems. and Metals Group			
Indust. Chems. Div.	Augusta, Ga.	118	Elemental
	Copperhill, Tenn.	1143	Pyrites; smelter gases
North American Petroleum Group	Lake Charles, La.	136	Sludge; hydrogen sulfide
Climax Chem. Co.	Monument, N.M.	68	Elemental; hydrogen sulfide
Columbia Nitrogen Corp.	Moultrie, Ga.	18	Elemental. May be closed.
Commonwealth Oil Refining Co., Inc.	Penuelas, P.R.	27	Elemental; sludge; hydrogen sulfide
Conserv, Inc.			
Conserv Chems. Div.	Nichols, Fla.	363	Elemental

Table A-4(continued). PRODUCERS OF SULFURIC ACID, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Coulton Chem. Corp.	Oregon, Ohio	163	Sludge
Cyprus Mines Corp.			
Bagdad Copper Co., div.	Bagdad, Ariz.	45	Elemental
Delta Chems., Inc.	Searsport, Me.	68	Elemental
Detroit Chem. Works			
Pressure Vessel Services, div.	Detroit, Mich.	32	Elemental
Diamond Shamrock Corp.			
Diamond Shamrock Oil and Gas Co.	Dumas, Tex.	32	Sludge; hydrogen sulfide
E. I. du Pont de Nemours & Co., Inc.			
Biochems. Dept.	La Porte, Tex.	318	Elemental; sludge
Indust. Chems. Dept.	Burnside, La.	463	Elemental; sludge
	Cleveland, Ohio	195	Elemental
	Cornwells Heights, Pa.	64	Elemental
	East Chicago, Ind.	340	Elemental; sludge
	Gibbstown, N.J.	100	Elemental
	Linden, N.J.	295	Elemental
	North Bend, Ohio	159	Elemental
	Richmond, Va.	85	Elemental
	Wurtland, Ky.	181	Elemental; sludge
Organic Chems. Dept.	Deepwater, N.J.	82	Elemental
Dyes and Chems. Div.	Newport, Ind.	114	Elemental. Operated for U.S Government
Polymer Intermediates Dept.			
Eagle Picher Indust., Inc.			
Agricultural Chems. Div.	Galena, Kans.	136	Elemental, smelter gases
Eastman Kodak Co.			
Eastman Chem. Products, Inc., subsid.			
Distillation Products Indust., div.	Rochester, N.Y.	5	Elemental; captive use
Esmark, Inc.			
Swift Chems. Co. Operation	Dothan, Ala.	27	Elemental
	Norfolk, Va.	54	Elemental
	Wilmington, N.C.	45	Elemental
Essex Chem. Corp.			
Chems. Div.	Newark, N.J.	163	Elemental; hydrogen sulfide
	Rumford, R.I.	18	Power plant stack gas emissions
Farmland Indust., Inc.	Green Bay, Fla.	1179	Elemental
First Mississippi Corp.			
First Miss, Inc., subsid.	Fort Madison, Iowa	463	Elemental
Freeport Minerals Co.			
Freeport Chem. Co., div.	Port Sulphur, La.	n.a	
	Uncle Sam, La.	1542	Elemental
Gardinier, Inc.			
U. S Phosphoric Products	Tampa, Fla.	1361	Elemental
Georgia-Pacific Corp			
Chem. Div.	Bellingham, Wash.	18	Elemental
W. R. Grace & Co.			
Agricultural Chems Group	Bartow, Fla.	771	Elemental
	Charleston, S.C.	36	Elemental - May be closed
Ochoa Fertilizer Co., Inc., subsid	Guanica, P.R.	127	Elemental - May be closed
Gulf Oil Corp.			
Gulf Oil Chems. Co., div.			
Petrochems. Div.	Port Arthur, Tex.	127	Sludge; hydrogen sulfide
Gulf Resources & Chem. Corp.			
The Bunker Hill Co., subsid.	Kellogg, Idaho	281	Smelter gases
Gulf + Western Indust., Inc.			
The New Jersey Zinc Co., subsid.	Palmerton, Pa.	145	Elemental, smelter gases
Illinois Power Co	Wood River, Ill.	17	Stack gases
Inspiration Consolidated Copper Co	Inspiration, Ariz.	227	Smelter gases
Internat'l Minerals & Chem. Corp.			
Marion Mfg. Corp., subsid.	Indianapolis, Ind.	59	Elemental
Kennecott Copper Corp.			
Metal Mining Div.			
Chino Mines Div.	Hurley, N.M.	181	Smelter gases
Ray Mines Div.	Hayden, Ariz.	250	Smelter gases
Utah Copper Div.	Salt Lake City, Utah	544	Smelter gases
Kerr-McGee Corp.	Grants, N.M.	64	Elemental
Kerr-McGee Chem. Corp., subsid.	Baltimore, Md.	100	Elemental - May be closed
	Cottondale, Fla.	27	Elemental - May be closed
L. J. & M. La Place Co.	Edison, N.J.	64	

Table A-4(continued). PRODUCERS OF SULFURIC ACID, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Minnesota Mining and Mfg. Co.			
Chem. Resources Div.	Copley, Ohio	84	Elemental
Mississippi Chem. Corp.	Pascagoula, Miss.	454	Elemental
Mobil Oil Corp.			
Mobil Chem. Co., div.			
Minerals Div.	Depue, Ill.	381	Elemental
Monsanto Co.			
Monsanto Commercial Products Co.		159	Elemental
Agricultural Div.	El Dorado, Ark.	123	Elemental; sludge; hydrogen sulfide
Monsanto Indust. Chems. Co.	Avon, Calif.	86	Elemental
	Everett, Mass.	308	Elemental
	Sauget, Ill.		
National Distillers and Chem. Corp.			
U. S. Indust. Chems. Co., div.	De Soto, Kans.	91	Elemental
	Dubuque, Iowa	64	Elemental
	Bartlesville, Okla.	82	Elemental; smelter gases
National Zinc Co.			
Newmont Mining Corp.			
Magma Copper Co., subsid.	San Manuel, Ariz.	590	Smelter gases
N L Indust., Inc.		272	Elemental
Titanium Pigment Div.	St. Louis, Mo.	544	Elemental
	Sayreville, N.J.	109	Elemental; sludge - May be closed
North Star Chems., Inc.	Pine Bend, Minn.		
Occidental Petroleum Corp.			
Occidental Chem. Co., subsid.			
Eastern Div.			
Southwest Region	Plainview, Tex.	91	Elemental
Occidental of Florida Div.	White Springs, Fla.	635	Elemental
Western Div.	Lathrop, Calif.	204	Elemental
Olin Corp.			
Agricultural Chems. Div.	Pasadena, Tex.	431	Elemental
Indust. Products and Services Div.	Baltimore, Md.	272	Elemental
	Beaumont, Tex.	172	Sludge; hydrogen sulfide
	North Little Rock, Ark.	82	Elemental
	Paulsboro, N.J.	209	Elemental; sludge
	Shreveport, La.	127	Elemental
	Tulsa, Okla.	109	
Ozark-Mahoning Co.			
Pfizer Inc.			
C. K. Williams & Co., div.	Easton, Pa.	14	Ferrous sulfate - High-purity iron oxides as by-product
	East St. Louis, Ill.	14	Ferrous sulfate - High-purity iron oxides as by-product
Phelps Dodge Corp.	Ajo, Ariz.	181	Smelter gases
	Hidalgo, N.M.	n.a	
	Morenci, Ariz.	245	Smelter gases
Western Nuclear, Inc., subsid.	Jeffrey City, Wyo.	32	Elemental
	Riverton, Wyo.	68	
Reichhold Chems., Inc.	Tuscaloosa, Ala.	68	Elemental - May be closed
Rohm and Haas Co.	Philadelphia, Pa.	82	Elemental - May be closed.
Rohm and Haas Texas, Inc., div.	Deer Park, Tex.	454	Recovery from methyl methacrylate
Royster Co.	Chesapeake, Va.	18	Elemental - May be closed
	Mulberry, Fla.	318	Elemental
St. Joe Minerals Corp.	Herculaneum, Mo.	91	Smelter gases
	Monaca, Pa.	259	Smelter gases
J. R. Simplot Co.			
Minerals and Chem. Div.	Pocatello, Idaho	726	Elemental; output cut back
Southern States Phosphate & Fertilizer Co.	Savannah, Ga.	32	Elemental
Standard Oil Co. of California	El Segundo, Calif.	136	Sludge; hydrogen sulfide
	Honolulu, Hawaii	36	Sludge; other
Standard Oil Co. (Indiana)			
Amoco Oil Co., subsid.	Texas City, Tex.	159	Elemental; sludge; hydrogen sulfide

Table A-4(continued). PRODUCERS OF SULFURIC ACID, THEIR ANNUAL CAPACITY AND RAW MATERIALS[1]

Company	Location	Annual capacity 1000 of tons	Raw material and remarks
Stauffer Chem. Co.			
Fertilizer and Mining Div.	Pasadena, Tex.	410	Elemental
Indust. Chem. Div.	Baton Rouge, La.	680	Elemental; sludge
	Baytown, Tex.	250	Elemental; sludge, hydrogen sulfide
	Dominguez, Calif.	295	Elemental; sludge; hydrogen sulfide
	Fort Worth, Tex.	109	Elemental
	Hammond, Ind.	250	Elemental; sludge
	Le Moyne, Ala.	191	Elemental
	Manchester, Tex.	1270	Elemental, sludge; hydrogen sulfide
Texaco Inc.	Martinez, Calif.	227	Elemental; sludge
Texasgulf, Inc.	Port Arthur, Tex.	66	Sludge; hydrogen sulfide
Agricultural Div.	Aurora, N.C.	1343	Elemental
Union Carbide Corp.			
Chems. and Plastics Div.	Texas City, Tex.	n.a.	
Union Oil Co. of California			
Collier Carbon and Chem. Corp. subsid.	Wilmington, Calif.	127	Elemental; sludge; hydrogen sulfide
United States Steel Corp.			
USS Agri-Chemicals div.	Bartow, Fla.	263	Elemental
	Fort Meade, Fla.	490	Elemental
	Wilmington, N.C.	86	Elemental - May be closed
USS Chems., div.	Neville Island, Pa.	45	Elemental; hydrogen sulfide
Valley Nitrogen Producers, Inc.	Helm, Calif.	254	Elemental
A F C Co., subsid.	Bena, Calif.	64	
Weaver Fertilizer Co., Inc.	Norfolk, Va.	45	Elemental
The Williams Companies			
Agrico Chem. Co., subsid.	Baltimore, Md.	23	
	Bay City, Mich.	36	
	Pierce, Fla.	635	
Wilson Pharmaceutical & Chem. Corp.			
INOLEX Chem. Div.	Elwood, Ill.	295	Elemental; sludge - Leased from U.S. Government - May close
Witco Chem. Corp.			
Sonneborn Div.	Petrolia, Pa.	41	Sludge
Wright Chem. Corp.	Acme, N.C.	54	Elemental - May be closed
	TOTAL	37478	

Source: Compiled in association with the *Chemical Economics Handbook*.

Table A-5. PRODUCERS OF OLEUM[2]

Allied Chemical Corp., Industrial Chemicals Division
American Cyanamid Co., Industrial Chemicals and Plastics Division
Corco Chemical Corp.
Stauffer Chemical Co., Industrial Chemical Division

Table A-6. SULFUR STATISTICS, 1973-1974[3]

(Thousands of tons)

Form	Production		Imports		Exports		Stocks	
	1973	1974	1973	1974	1973	1974	1973	1974
Elemental sulfur	2455	2570	1242	2235	1805	2642	3990	3861
Frasch	7725	8062						
Pyrites	215	N.A.	-	N.A.				
Smelter acid	610	N.A.						
H_2S acid and SO_2	-	-						
Other	neg.	neg.						

APPENDIX B

PRODUCT USES AND PROPERTIES

Table B-1. PHYSICAL PROPERTIES OF SULFUR, SULFUR DIOXIDE, SULFUR TRIOXIDE, AND SULFURIC ACID[4,5]

Property	Sulfur[a]	Sulfur dioxide[b]	Sulfur trioxide[b]	Sulfuric acid[b]
Physical state		Colorless gas[c]	Colorless liquid or crystals	Colorless liquid
Molecular weight	32.06	64.07	80.06	98.06
Specific gravity at 0°C	2.06 (α sulfur) 1.96 (β sulfur)	1.434 (liquid)		1.834 at 20°C
Melting point in °C	112.8 (α sulfur) 119 (β sulfur)	-72.7	16.83	10.5
Boiling point	-	-10.0	44.8	
Vapor density (air=1)	-	2.3	2.8	
Solubility	Insoluble in water	0.6gm in 100gm of H_2O at 90°C, 8.5gm in 100gm at 25°C and 22.8gm in 100gm at 0°C.	Up to 100 percent sulfuric acid in water	

[a] Reference 4.

[b] Reference 5.

[c] The gas has a characteristic taste and odor.

Table B-2. SULFUR USES IN 1972[a,6]

Use	Quantity, million tons
Agriculture (fertilizers)	5.29
Plastic and synthetic products	0.55
Paper products	0.35
Paints	0.40
Nonferrous metal production	0.44
Explosive	0.26
Petroleum refining	0.22
Iron and Steel production	0.11
Other	2.37

[a] Approximately 90 percent of the sulfur consumed was in the form of sulfuric acid.

Table B-3. COMMERCIAL STRENGTHS OF SULFURIC ACID[7]

For oleums, % means free SO_3	Degrees Be, 60°F, or 15.6°C	Specific gravity, 60°F, or 15.6°C	Sulfuric acid, %
Battery acid	29.0	1.250	33.33
Chamber acid, fertilizer acid, 50 acid	50	1.526	62.18
Glover or tower acid, 60 acid	60	1.706	77.67
Oil of vitriol (OV), concentrated acid, 66 acid	66	1.835	93.19
98 acid		1.841	98.0
100% H_2SO_4		1.835	100.0
20% oleum, 104.5 acid		1.915	104.50
40% oleum, 109 acid		1.983	109.0
66% oleum		1.992	114.6

APPENDIX C

REFERENCES FOR APPENDICES

REFERENCES FOR APPENDICES

1. Standford Research Institute. 1974 Dictionary of Chemical Producers. United States of America. California 1974.

2. Chemical Marketing Reporter. 1974-75 OPD Chemical Buyers Dictionary. 62nd Annual Edition C 1974, Schnel Publications Co., Inc. New York.

3. Chemical Economics Handbook. Manual of Current Indicators. February 1975.

4. Gessner, G. Hawley. The Condensed Chemical Dictionary. 8th Edition. New York. Van Nostrand Reinhold Company. 1971.

5. Patty, F. A. Arsenic, Phosphorus, Selenium, Sulfur, and Tellurium. In: Industrial Hygiene and Toxicology. New York, Interscience Publishers. 1968.

6. Sulfur. In: Commodity Statement. U.S. Department of Interior. Bureau of Mines.

7. Shreve, R. N. Sulfur and Sulfuric Acid. In: Chemical Process Industries. New York, McGraw Hill Book Company. 1967.